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Summary of recommendations for the haemodynamic and angiographic assessment of the pulmonary circulation. Joint statement of the Polish Cardiac Society's Working Group on Pulmonary Circulation and Association of Cardiovascular Interventions

Standardy hemodynamicznej i angiograficznej oceny krążenia płucnego. Wspólne stanowisko Sekcji Krążenia Płucnego i Asocjacji Interwencji Sercowo-Naczyniowych Polskiego Towarzystwa Kardiologicznego

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Abstract

Right heart catheterisation (RHC) is the 'gold standard' for haemodynamic assessment of the pulmonary circulation. For the diagnosis of pulmonary hypertension (PH), the guidelines of the European Society of Cardiology require a mean pulmonary arterial pressure ≥ 25 mm Hg to be confirmed by direct haemodynamic measurement. Additionally, RHC provides a lot of valuable information about the differential diagnosis and severity of PH, and also helps determine the patient's prognosis. Acute vasoreactivity testing performed in patients with pulmonary arterial hypertension is intended to identify the group of patients who should be treated with calcium channel blockers. Patients referred for heart transplantation require advanced pulmonary vascular disease to be ruled out either on resting examination or during vasoreactivity testing. RHC is a component of such interventional procedures as balloon atrial septostomy, closure of intracardiac shunts in congenital heart and great vessel defects, valvuloplasty for pulmonary valve stenosis, and pulmonary angioplasty. Pulmonary angiography is an examination recommended when selecting patients for pulmonary endarterectomy or balloon pulmonary angioplasty in thromboembolic PH. Due to the dynamic growth in the number of patients diagnosed with and treated for PH in Poland, the Boards of the Polish Cardiac Society's Working Group on Pulmonary Circulation and Association of Cardiovascular Interventions have undertaken a joint project to develop recommendations to standardise guidelines for RHC procedure, acute vasoreactivity testing and pulmonary angiography at cardiac wards and haemodynamic laboratories in Poland. This document has been prepared by experts delegated by the Working Group on Pulmonary Circulation and the Association of Cardiovascular Interventions, and subsequently approved by the Boards of both organs of the Polish Cardiac Society.

Key words: pulmonary hypertension, right heart catheterisation, pulmonary angiography, acute vasoreactivity test

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INTRODUCTION

Right heart catheterisation (RHC) remains an essential examination to diagnose pulmonary hypertension (PH), to assess the patient's prognosis, and to select patients for procedural treatment of PH, congenital heart defects and heart transplantation [1]. Due to the dynamic growth in the number of patients diagnosed with and treated for PH in Poland, experts from the Polish Cardiac Society's Working Group on Pulmonary Circulation and Association of Cardiovascular Interventions have undertaken a joint project to develop recommendations to standardise guidelines for RHC procedure, acute vasoreactivity testing (AVT) and pulmonary angiography at cardiac wards and haemodynamic laboratories in Poland. The complete guidelines are presented in a separate publication [1]. What follows is a summary of the key recommendations.

RIGHT HEART CATHETERISATION

The usefulness of RHC depends on the aetiology of PH [2, 3]. Nevertheless, it is an examination which should be performed in order to confirm the diagnosis of PH. RHC should be preceded by echocardiography with an estimate of the likelihood of PH. No pulmonary arterial hypertension (PAH)-specific drug therapy should be initiated until PH is confirmed by RHC. Control RHC should be performed in patients with PAH in the case of clinical aggravation, after causes other than progression of PAH have been ruled out, in order to consider modifying the patient's current therapy.

It is recommended that RHC be performed in a haemodynamic laboratory, in a hybrid operating room equipped with an angiocardiograph, or in another room equipped with X-ray fluoroscopy, a device for invasive measurements of blood pressure, and cardiopulmonary resuscitation equipment. During the procedure, the patient should be continuously monitored for cardiovascular and respiratory disorders. Prior to the procedure, the patient should be fasted for at least 4–6 h. Physical examination and medical interview should be performed, and the patient's informed consent to the procedure should be obtained in writing. While zeroing to atmospheric pressure, transducers should be positioned at the mid-chest level. RHC procedures are normally performed under local anaesthesia, most often with lidocaine 2%. Usually, central venous access is used, obtained via the internal jugular, subclavian, or femoral vein. Access through the basilic vein is chosen less frequently. Access via the right internal jugular vein is the easiest way to insert a Swan-Ganz catheter into the pulmonary artery. RHC catheter insertion via the femoral access can be more difficult than via the veins of the upper part of the body, although the former approach may be preferred in patients at a higher risk of haemorrhagic complications. Before obtaining vascular access, ultrasound may be performed to confirm the location of the vein. Pressures in the cardiac chambers are measured during free breathing, while the value of pulmonary artery wedge pressure (PAWP) should be measured at the end of expiration. Normally cardiac output (CO) is measured by thermodilution. If three consecutive measurements of CO do not differ by more than 10%, the measurements can be considered reliable. We suggest using the mean value from the last three measurements as the final result of the CO measurement. Oximetry measurements in the superior vena cava and pulmonary artery during the first RHC in the patient with PAH can be considered in order to detect any left-to-right shunt.

In the presence of cardiac shunt defects, CO should be measured by the Fick method. It is also possible to estimate oxygen consumption on the basis of the patient's age, gender and body surface area according to the formula proposed by Bergsta [4], or on the basis of body surface area (BSA × 125 mL/min or BSA × 110 mL/min in elderly patients) [5]. For quantification of intracardiac shunt volume, the pulmonary (Qp) to systemic flow (Qs) ratio should be calculated in order to select patients for treatment. According to current guidelines, a pulmonary to systemic flow ratio of more than 1.5 indicates the presence of a significant shunt. In patients with cardiac shunt defects, it is recommended that a complete oximetry run be performed. Angiocardiography can be of decisive importance in the case of ambiguous results of non-invasive examinations to either confirm or exclude the presence of a shunt between cardiac chambers or vascular fistulae in the pulmonary circulation. Contrast-enhanced angiocardiography is not routinely used in adults. However, it is a very good method for visualising extracardiac shunts such as pulmonary arteriovenous fistulae.

After the procedure, the patient should routinely remain in a semisupine position for 2–3 h with light compression applied to the vascular access site.

Contraindications to RHC

Contraindications to RHC include:

- severe haemorrhagic diathesis;
- anticoagulant therapy with International Normalisation Ratio > 2 (relative contraindication);
- uncorrected electrolyte disturbances (hypo- or hyperkalaemia);
- when non-invasive examinations may be performed as a substitute for RHC;
- severe ventricular and supraventricular arrhythmias;
- advanced and complete atrioventricular block;
- caution should be exercised in patients with left bundle branch block, as complete heart block is a possible occurrence.

Normal haemodynamic parameters of the pulmonary circulation

Normal haemodynamic parameters of the pulmonary circulation are shown in Table 1. According to the current definition, PH is considered a condition with a mean pulmonary arterial

Table 1. Normal haemodynamic parameters of the pulmonary circulation

Parameter	Value (range)
Pressure: pulmonary artery	
Systolic	15–30 mm Hg
Mean	8–20 mm Hg
Diastolic	3–12 mm Hg
Right atrium, mean	0–8 mm Hg
Left atrium, mean	2–12 mm Hg
Pulmonary artery wedge pressure	4–15 mm Hg
Left ventricular end-diastolic pressure	5–12 mm Hg
Cardiac output	4–8 L/min
Cardiac index	2.5–4.2 L/min/m^2
Pulmonary vascular resistance	< 2.5 WU
Total pulmonary resistance	< 3.5 WU
Pulmonary vascular resistance index	< 3.0 WU
Systemic vascular resistance	10–20 WU
Oxygen saturation of blood in the pulmonary trunk	70–80%

pressure (mPAP) of at least 25 mm Hg. In the population of patients with systolic or diastolic left ventricular (LV) dysfunction revealed by echocardiography, and with risk factors of heart failure with preserved LV systolic function, in the case of a PAWP ≤ 15 mm Hg we suggest supplementing cardiac catheterisation by direct measurement of LV end-diastolic pressure [6]. Observing the effect of intravenous administration of 500 mL NaCl 0.9% over 5–10 min on the PAWP value can also be considered [7]. There is no sufficiently documented data to define the limit of pressure in the pulmonary artery which would allow the diagnosis of PH on exercise.

Complications associated with pulmonary artery catheterisation

Complications of RHC can be classified into those related to vascular access, those related to catheter manipulation when advancing it through the cardiac chambers, and those related to catheter placement in the pulmonary bed.

In 2006, Hoeper et al. [8] published results of a study on the risk of complications associated with planned RHC, pressure measurements and vasoreactivity testing in patients with PH of various aetiologies. The study analysed 7,218 RHC procedures. Death occurred in four (0.055%) patients, but only in two cases was it directly related to the procedure (rupture of the pulmonary artery when measuring wedge pressure and bleeding into the lungs after pulmonary angiography). The incidence of all adverse events in the study population was 1.1%. 38% of complications were related to venous access, 29% to the catheterisation itself, and 20% to AVT. Types and incidence of complications associated with RHC are shown in Table 2.

Table 2. Types and incidence of complications associated with right heart catheterisation [8]

Types and incidence of complications	Incidence [%]
Central venous access-related	
Accidental puncture of an artery	≤ 3.6
Haematoma	5.3
Neuropathy	0.1–1.1
Pneumothorax	0.3–1.9
Air embolism	0.5
Catheterisation-related	
Benign arrhythmias	> 20
Malignant arrhythmias	0.3–3.8
Mild worsening of tricuspid regurgitation	17
Right bundle branch block	0.1–4.3
Complete heart block (in the initial presence of left bundle branch block)	0–8.5
Venous thrombosis	0.5–3
Catheter-related	
Pulmonary artery rupture	0.03–0.7
Infectious complications — sepsis	0.7–3.0
Infective endocarditis	2.2–7.1
Pulmonary infarction	0.1–2.6
Intramural haematoma	28–61
Death	0.02–1.5

PULMONARY VASOREACTIVITY TESTING

AVT is a diagnostic procedure used to assess the preserved ability of the pulmonary arterial bed to vasodilate under the action of substances considered to be referential.

AVT performed in patients with PAH is used to predict a beneficial effect of calcium channel blocker therapy [9]. AVT of the pulmonary arteries should be performed in every patient with idiopathic or familial PAH prior to the initiation of therapy [10]. AVT of the pulmonary arteries can be considered in patients with other types of PAH. However, the likelihood of a positive response to the test and long-term benefits of calcium channel blocker therapy is low.

A positive acute response in patients with PAH is defined as a decrease in mPAP of at least 10 mm Hg to reach a value below 40 mm Hg, with no significant decrease in CO [11].

The substance of first choice for AVT of the pulmonary arteries in PAH appears to be nitric oxide (NO). It is administered in the respiratory mixture, at a concentration of 10–20 ppm for 5 min [2].

Vasoreactivity testing may be also performed using:

— iloprost nebulised via a dedicated nebuliser at a dose of 5 μg measured in the mouthpiece; haemodynamic measurements should be performed within 15 min after the beginning of nebulisation [12, 13];

— adenosine administered in continuous intravenous infusion at an initial dose of 50 μg/kg BW/min, titrated by 50 μg at 2-min intervals to a maximum dose of 350 μg/kg BW/min or to the maximum tolerated dose [2];
— epoprostenol administered in intravenous infusion at an initial dose of 2 ng/kg BW/min, titrated by 2 ng/kg BW/min at 10-min intervals to a maximum dose of 10 ng/kg BW/min [2].

Calcium channel blocker treatment is contraindicated in patients without prior confirmation of preserved reactivity of the pulmonary arterial bed.

In the group of patients with **cardiac shunt defects,** a baseline pulmonary vascular resistance index (PVRI) < 6 Wood units (WU)/m² and a ratio of pulmonary vascular resistance (PVR) to systemic vascular resistance (SVR) (PVR/SVR < 0.3) is considered indicative of a favourable outcome immediately following surgery. A positive outcome is also observed in patients with a PVRI of between 6 and 9 WU/m² and/or a PVR/SVR > 0.3–0.5. However, these values decrease during NO inhalation at a low or moderate concentration (20–40 ppm) by at least 20% and below the lower limits of these ranges. If the baseline PVRI is > 9 WU/m² or the PVR/SVR is > 0.5, then the risk of perioperative complications is significant [14, 15] even when the reactivity criteria are met. Correction of a congenital shunt defect can be performed without additional haemodynamic tests in patients with a PVRI < 4 WU/m² or a PVR < 2.3 WU. If the PVRI is > 8 WU/m² or the PVR is > 4.6 WU, the shunt should not be corrected. In the setting of intermediate values, AVT of the pulmonary arteries or the balloon occlusion test can be considered. Based on the current data, no preferable methodology of these tests or criteria for a positive test result can be recommended. The authors of the document recommend that, until data from long-term randomised studies in patients with PH due to congenital heart diseases is published, drugs and their methods of administration recommended for the diagnostics of idiopathic PAH should be used [16]. Shunt closure is contraindicated in patients with Eisenmenger syndrome [17].

When **selecting patients for heart transplantation**, RHC and AVT are the standard procedures. A PVR > 5 WU, a PVRI > 6 WU/m² and a transpulmonary pressure gradient (TPG) > 16 mm Hg is considered a contraindication for transplantation due to a very high risk of early post-transplant mortality caused by right ventricular failure. According to the International Society for Heart and Lung Transplantation, AVT should be performed when the PVR is > 3 WU, TPG > 15 mm Hg, systolic PAP > 50 mm Hg, and systemic systolic arterial pressure not lower than 85 mm Hg [9]. Nevertheless, it is worth performing AVT at earlier stages of PH — when the PVR is > 2.5 WU, and TPG > 12 mm Hg [18]. If during AVT, previously increased PVR decreases to < 2.5 WU, heart transplantation becomes possible provided that that is not accompanied by a fall in systemic blood pressure < 85 mm Hg. If the decrease in the PVR is accompanied by systemic hypotension, the patient still remains at risk of early post-operative right ventricular failure and increased perioperative mortality [19]. The definition of pulmonary vasoreactivity and reversibility of PH in heart transplant candidates differs from that in the case of PAH. In orthotopic heart transplantation (OHT) candidates, PH is considered reversible if in AVT with one of the aforementioned substances a PVR < 2.5–3 WU and a TPG < 12 mm Hg is achieved, with no fall in systemic systolic arterial pressure below 85 mm Hg as assessed by direct measurement. Sodium nitroprusside (SNP) is administered via an infusion pump at specific doses and time intervals (Table 3) to reduce initially increased PVR and TPG values, without reducing systemic systolic pressure below 85 mm Hg. The prognostic value of AVT with SNP in OHT candidates has been confirmed by Costard-Jackle and Fowler [20].

Table 3. Dosage of sodium nitroprusside (SNP) and duration of each stage of acute vasoreactivity testing when selecting patients for orthotopic heart transplantation

Dose of SNP	Duration of administration
0.25 μg/kg BW/min	3–5 min
0.5 μg/kg BW/min	3–5 min
1.0 μg/kg BW/min	3–5 min
1.5 μg/kg BW/min	3–5 min
2.0 μg/kg BW/min	3–5 min
2.5 μg/kg BW/min	3–5 min
3.0 μg/kg BW/min	3–5 min

In AVT prior to OHT, also NO [21–23], sildenafil [24, 25], iloprost and milrinone may be used.

PULMONARY ANGIOGRAPHY

Pulmonary angiography is the 'gold standard' in the diagnostics of chronic thromboembolic pulmonary hypertension (CTEPH). It should be performed in patients with ambiguous results of non-invasive imaging examinations, as well as in candidates for procedural treatment of CTEPH (i.e. pulmonary endarterectomy or percutaneous pulmonary angioplasty) [26]. Pulmonary angiography should be performed after haemodynamic assessment of the pulmonary circulation and from the same vascular access as in RHC. The most common catheter used for angiography is the pigtail catheter. Contrast agent is selectively administered into the right and left pulmonary artery via an automatic pump under a maximum pressure of 600–900 psi. For a single administration, 30–50 mL of contrast agent given at a rate of 10–25 mL/s is usually used. Advanced right heart failure requires the administration of a smaller volume of contrast agent at a lower flow rate. It is recommended that the right and the left pulmonary artery be selectively visualised in at least two projections using a large-field image intensifier and with the use of nonionic and low-osmolar contrast

agents. Two projections are normally obtained for each lung: posterior-anterior and lateral or oblique (45 degrees) [27]. In order to reduce contrast volume, subtraction angiography may be performed. Pulmonary angiography can be performed relatively safely even in patients with severe PH and right ventricular failure [28] provided that standard recommendations are followed and the operator is appropriately experienced. Classic angiographic lesions indicating CTEPH include pouch defects, webs and bands, luminal irregularities and abrupt vessel narrowing, as well as occlusion of the artery at its orifice [29]. Pulmonary artery obstruction or occlusion is usually accompanied by a decrease in, or lack of, pulmonary parenchymal perfusion. When described, segmental pulmonary arteries should be numbered according to the pulmonary segments that they vascularise. Given that angiographic results are the primary criterion for operability of CTEPH, imaging should be optimised.

However, as it is an invasive examination with a risk of complications, classic pulmonary angiography is rarely used **in the diagnostics of acute pulmonary embolism** [30]. The protocol for angiography in acute pulmonary embolism involves selective administration of contrast agent (30–50 mL) into the right and left pulmonary artery by an automatic injector (15–25 mL/s). The diagnostic criteria for acute pulmonary embolism at pulmonary angiography include contrast filling defects or amputation of the pulmonary artery, which are indicative of a thrombus. In patients with high-risk pulmonary embolism, pulmonary angiography may precede percutaneous pulmonary embolectomy. After pulmonary angiography, the patient should be monitored for at least 24 h.

FORMAL REQUIREMENTS, CERTIFICATION OF PHYSICIANS AND RHC LABORATORIES

Currently, there are no precise recommendations for the number of RHC procedures needed to obtain and maintain their adequate quality [31–34].

To ensure the quality of RHC procedures and their maximum standardisation, the authors of these guidelines have decided to develop training requirements for RHT specialists. The training is completed with the title of Certified Right Heart Catheterisation Specialist.

Requirements for the Right Heart Catheterisation Certificate (Right Heart Catheterisation Specialist — RHCS)

1. The RHCS Certificate can be obtained by an internist, a cardiologist (including paediatric cardiologist), a cardiac surgeon, an anaesthesiologist or a resident (after at least two years of residency) trained in one of the aforementioned specialties, who is a member of the Association of Cardiovascular Interventions of the Polish Cardiac Society or the Working Group on Pulmonary Circulation of the Polish Cardiac Society.
2. The training should be conducted under the supervision of the Head of the Certified Right Heart Catheterisation Laboratory and/or a person who has already obtained the title of RHCS.
3. In order to obtain the title of RHCS, a physician has to independently perform and interpret at least 75 examinations.
4. The examinations performed should be documented in the database of the Association of Cardiovascular Interventions of the Polish Cardiac Society or in a procedure log book (if the Laboratory does not have access to the database of the Association of Cardiovascular Interventions).
5. During the training, the trainee is required to undergo a course at the Certified Laboratory. It is also recommended for an internship to be completed at a centre performing AVT to select patients for heart transplantation, and with accreditation for transplant procedures.
6. An application for the certificate is to be submitted by the head of the laboratory or the training supervisor. The application shall be accompanied by a declaration confirming the number of procedures performed and confirming completion of the training.
7. The certificate is signed by the Chairman of the Working Group on Pulmonary Circulation and by the Chairman of the Association of Cardiovascular Interventions of the Polish Cardiac Society.

Requirements for the accreditation of Right Heart Catheterisation Referral Laboratories

1. Having accreditation (a certificate) as a RHC Referral Laboratory confirms the high quality of the procedures performed, and ensures patient safety and the repeatability of results of catheterisation performed according to the established and described standards.
2. RHC Referral Laboratory Certificates are issued by the Executive Board of the Polish Cardiac Society at the request of the Board of the Working Group on Pulmonary Circulation and/or by the Board of the Association of Cardiovascular Interventions.
3. An application is to be submitted by the Head of the Laboratory, together with an enclosed declaration of compliance with relevant criteria, and with other documents as set forth in these requirements.

Equipment:

— Angiocardiograph with digital image recording
— Polyphysiograph (enabling measurement of pressures and ECG recording)
— Pulse oximeter
— Defibrillator, resuscitation equipment
— External or endocavitary cardiac stimulator
— Device for the administration of drugs used in acute haemodynamic testing (NO or iloprost, or SNP)
— Device for measuring arterial blood gases at the location

Procedures:

— At least 50 RHC procedures per year, including at least 20 with acute reversibility testing

— Participation in non-commercial scientific programmes on PH

Personnel:

— At least two operators, including at least one with the RHCS certificate

Conflict of interest: *none declared*

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